Appendix C

System Descriptions

This appendix addresses the characteristics, capabilities, and limitations of existing and proposed common-use radionavigation systems. The systems covered are:

- GPS
- GPS Augmentations
- Loran-C
- VOR, VOR/DME, and TACAN
- ILS
- MLS
- Aeronautical Nondirectional Beacons
- Maritime Radiobeacons

C.1 System Parameters

All of the systems described are defined in terms of system parameters that determine the use and limitations of the individual navigation system's signal-in-space. These parameters are:

- Signal Characteristics
- Accuracy
- Availability
- Coverage
- Reliability
- Fix Rate
- Fix Dimensions
- System Capacity
- Ambiguity
- Integrity

C.1.1 *Signal Characteristics*

Signals-in-space are characterized by power levels, frequencies, signal formats, data rates, and any other information sufficient to completely define the means by which a user derives navigation information.

C.1.2 *Accuracy*

In navigation, the accuracy of an estimated or measured position of a craft (vehicle, aircraft, or vessel) at a given time is the degree of conformance of that position with the true position of the craft at that time. Since accuracy is a statistical measure of performance, a statement of the accuracy of a navigation system is meaningless unless it includes a statement of the uncertainty in position that applies.

Statistical Measure of Accuracy

Navigation system errors generally follow a known error distribution. Therefore, the uncertainty in position can be expressed as the probability that the error will not exceed a certain amount. A thorough treatment of errors is complicated by the fact that the total error is comprised of errors caused by instability of the transmitted signal, effects of weather and other physical changes in the propagation medium, errors in the receiving equipment, and errors introduced by the human navigator. In specifying or describing the accuracy of a system, the human errors usually are excluded. Further complications arise because some navigation systems are linear (one-dimensional) while others provide two or three dimensions of position.

When specifying linear accuracy, or when it is necessary to specify requirements in terms of orthogonal axes (e.g., along-track or cross-track), the 95 percent confidence level will be used. Vertical or bearing accuracies will be specified in one-dimensional terms (2 sigma), 95 percent confidence level.

When two-dimensional accuracies are used, the 2 drms (distance root mean squared) uncertainty estimate will be used. Two drms is twice the radial error drms. The radial error is defined as the root-mean-square value of the distances from the true location point of the position fixes in a collection of measurements. It is often found by first defining an arbitrarily oriented set of perpendicular axes, with the origin at the true location point. The variances around each axis are then found, summed, and the square root computed. When the distribution of errors is elliptical, as it often is for stationary, ground-based systems, these axes can be taken for convenience as the major and minor axes of the error ellipse. Then the confidence level depends on the elongation of the error ellipse. As the error ellipse collapses to a line, the confidence level of the 2 drms measurement approaches 95 percent; as the error ellipse becomes circular, the confidence level approaches 98 percent. The GPS 2 drms accuracy will be at 95 percent probability.

DOD specifies horizontal accuracy in terms of Circular Error Probable (CEP—the radius of a circle containing 50 percent of all possible fixes). For the FRP, the conversion of CEP to 2 drms has been accomplished by using 2.5 as the multiplier.

Types of Accuracy

Specifications of radionavigation system accuracy generally refer to one or more of the following definitions:

- Predictable accuracy: The accuracy of a radionavigation system's position solution with respect to the charted solution. Both the position solution and the chart must be based upon the same geodetic datum. (Note: Appendix D discusses reference systems and the risks inherent in using charts in conjunction with radionavigation systems).
- Repeatable accuracy: The accuracy with which a user can return to a position whose coordinates have been measured at a previous time with the same navigation system.
- Relative accuracy: The accuracy with which a user can measure position relative to that of another user of the same navigation system at the same time.

C.1.3 Availability

The availability of a navigation system is the percentage of time that the services of the system are usable by the navigator. Availability is an indication of the ability of the system to provide usable service within the specified coverage area. Signal availability is the percentage of time that navigation signals transmitted from external sources are available for use. It is a function of both the physical characteristics of the environment and the technical capabilities of the transmitter facilities.

C.1.4 Coverage

The coverage provided by a radionavigation system is that surface area or space volume in which the signals are adequate to permit the navigator to determine position to a specified level of accuracy. Coverage is influenced by system geometry, signal power levels, receiver sensitivity, atmospheric noise conditions, and other factors which affect signal availability.

C.1.5 Reliability

The reliability of a navigation system is a function of the frequency with which failures occur within the system. It is the probability that a system will perform its function within defined performance limits for a specified period of time under given operating conditions. Formally, reliability is one minus the probability of system failure.

C.1.6 Fix Rate

The fix rate is defined as the number of independent position fixes or data points available from the system per unit time.

C.1.7 Fix Dimensions

This characteristic defines whether the navigation system provides a linear, one-dimensional line-of-position, or a two-or three-dimensional position fix. The ability of the system to derive a fourth dimension (e.g., time) from the navigation signals is also included.

C.1.8 System Capacity

System capacity is the number of users that a system can accommodate simultaneously.

C.1.9 Ambiguity

System ambiguity exists when the navigation system identifies two or more possible positions of the vehicle, with the same set of measurements, with no indication of which is the most nearly correct position. The potential for system ambiguities should be identified along with provision for users to identify and resolve them.

C.1.10 Integrity

Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation.

C.2 System Descriptions

This section describes the characteristics of those individual radionavigation systems currently in use or under development. These systems are described in terms of the parameters previously defined in Section C.1. All of the systems used for civil navigation are discussed. The systems that are used exclusively to meet the special applications of DOD are discussed in the CJCS MPNTP.

C.2.1 GPS

GPS is a space-based dual use military/civil radionavigation system that is operated for the Government of the United States by the U.S. Air Force. The U.S. Government provides two levels of GPS service. The Precise Positioning Service (PPS) provides full system accuracy to authorized users. The Standard Positioning Service (SPS) is designed to provide accurate positioning to all users throughout the world.

The GPS has three major segments: space, control, and user. The GPS Space Segment is composed of 24 satellites in six orbital planes. The satellites operate in circular 20,200 km (10,900 nm) orbits at an inclination angle of 55 degrees and with a 12-hour period.

The GPS Control Segment has five monitor stations and four dedicated ground antennas with uplink capabilities. The monitor stations use a GPS receiver to passively track all satellites in view and accumulate ranging data from the satellite signals. The information from the monitor stations is processed at the Master Control Station (MCS) to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via the ground antennas, which are also used for transmitting and receiving health and control information.

The GPS User Segment consists of a variety of configurations and integration architectures that include an antenna and receiver-processor to receive and compute navigation solutions to provide positioning, velocity, and precise timing to the user.

The characteristics of GPS are summarized in Table C-1.

A. Signal Characteristics

Each satellite transmits three separate spectrum signals on two L-band frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). L1 carries a Precise P (Y) Pseudo-Random Noise (PRN) code and a Coarse/Acquisition (C/A) PRN code; L2 carries the P(Y) PRN code. (The Precise code is denoted as P(Y) to identify that this PRN code can be operated in either a clear unencrypted "P" or an encrypted "Y" code configuration.) Both PRN codes carried on the L1 and L2 frequencies are phase-synchronized to the satellite clock and modulated (using modulo two addition) with a common 50 Hz navigation data message.

The SPS ranging signal received by the user is a 2.046 MHz null-to-null bandwidth signal centered about L1. The transmitted ranging signal that comprises the GPS-SPS is not limited to the null-to-null signal and extends through the band 1563.42 to 1587.42 MHz. The minimum SPS received power is specified as -160.0 dBW. The navigation data contained in the signal are composed of satellite clock and ephemeris data for the transmitting satellite plus GPS constellation almanac data, GPS to UTC (USNO) time offset information, and ionospheric propagation delay correction parameters for single frequency users. The entire navigation message repeats every 12.5 minutes. Within this 12.5-minute repeat cycle, satellite clock and ephemeris data for the transmitting satellite are sent 25 separate times so they repeat every 30 seconds. As long as a satellite indicates a healthy status, a receiver can continue to operate using these data for the validity period

Table C-1. GPS/SPS Characteristics (Signal-in-Space)

SPS ACCURACY (METERS) 95%*			SERVICE		SERVICE	FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	RELATIVE***	AVAILABILITY*	COVERAGE*	RELIABILITY**	RATE	DIMENSION	CAPACITY	POTENTIAL
Horz ≤ 100 Vert ≤.156 Time ≤ 340ns	Horz ≤ 141 Vert ≤ 221	Horz ≤ 1.0 Vert ≤ 1.5	99.85%	99.90% (PDOP ≤ 6)	99.97%	1-20 per second	3D + Time	Unlimited	None

* *Accuracy, availability, and coverage percentages are computed using 24 hour measurement intervals. Accuracy is the average for any point on the globe. Availability and coverage are global averages. Use 99.16% and 96.90%, respectively, for availability and coverage when computing percentages for worst-case point on globe.*
** *500 meter not to exceed predictable horizontal error reliability threshold. Reliability measurement interval is one year, averaged from daily values over the globe. Use 99.79% when daily averages are computed from the worst-case point on the globe.*
*** *Receivers using the same satellites with position solutions computed at approximately the same time.*

SYSTEM DESCRIPTION: GPS is a space-based radio positioning navigation system that provides three-dimensional position and time information to suitably equipped users anywhere on or near the surface of the Earth. The space segment consists of 24 satellites in 6 orbital planes of 12-hour periods. Each satellite transmits navigation data and time signals on 1575.42 and 1227.6 MHz. 1227.6 MHz is reserved for authorized users; therefore, data are encrypted and not available for private civil use. For more detail, refer to Ref. 10.

of the data (up to 4 or 6 hours). The receiver will update these data whenever the satellite and ephemeris information are updated - nominally once every 2 hours.

The concept of GPS position determination is based on the intersection of four separate vectors each with a known origin and a known magnitude. Vector origins for each satellite are computed based on satellite ephemeris. Vector magnitudes are calculated based on signal propagation time delay as measured from the transmitting satellite's PRN code phase delay. Given that the satellite signal travels at nearly the speed of light and taking into account delays and adjustment factors such as ionospheric propagation delays and earth rotation factors, the receiver performs ranging measurements between the individual satellite and the user by dividing the satellite signal propagation time by the speed of light.

B. Accuracy

GPS provides two services for position determination, SPS and PPS. Accuracy of a GPS fix varies with the capability of the user equipment.

1. Standard Positioning Service (SPS)

SPS is the standard specified level of positioning and timing accuracy that is available, without restrictions, to any user on a continuous worldwide basis. SPS provides a predictable positioning accuracy of 100 meters (95 percent) horizontally and 156 meters (95 percent) vertically and time transfer accuracy to UTC within 340 nanoseconds (95 percent). Decisions to change operational modes of GPS to include degrading GPS accuracy to civil users will be made by the NCA.

2. Precise Positioning Service (PPS)

PPS is the most accurate direct positioning, velocity, and timing information continuously available, worldwide, from the basic GPS. This service is limited by the DOD to users who are specifically authorized access. P(Y) code capable user equipment provides a predictable positioning accuracy of at least 22 meters (95 percent) horizontally and 27.7 meters vertically and time transfer accuracy to UTC within 200 nanoseconds (95 percent).

C. Availability

Provided there is coverage as defined below, SPS will be available 99.85 percent of the time.

D. Coverage

GPS coverage is worldwide. The probability that 4 or more GPS satellites are in view anywhere on or near the earth (over any 24-hour period) with a PDOP of 6 or less, and with at least a 5 deg mask angle, is 99.90 percent.

E. Reliability

If the conditions on coverage and service availability are met, the probability that the horizontal positioning error will not exceed 500 meters is 99.97 percent.

F. Fix Rate

The fix rate is essentially continuous, but the need for receiver processing to retrieve the spread-spectrum signal from the noise results in an actual users fix rate of 1-20 per second. Actual time to a first fix depends on user equipment capability and initialization with current satellite almanac data.

G. Fix Dimensions

GPS provides three-dimensional positioning and time when four or more satellites are available and two-dimensional positioning when only three satellites are available.

H. System Capacity

The capacity is unlimited.

I. Ambiguity

There is no ambiguity.

J. Integrity

DOD GPS receivers use the information contained in the navigation and health messages, as well as self-contained satellite geometry software programs and internal navigation solution convergence monitors, to compute an estimated figure of merit. This number is continuously displayed to the operator, indicating the estimated overall confidence level of the position information. Receiver Autonomous Integrity Monitoring (RAIM), a receiver algorithm, is one method to satisfy integrity requirements.

C.2.2 Augmentations to GPS

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, accidental perturbations of signal timing, or other factors.

The basic GPS must be augmented to meet current civil aviation, land and marine integrity requirements. DGPS is one method to satisfy integrity requirements.

DGPS enhances GPS through the use of differential corrections to the basic satellite measurements. DGPS is based upon accurate knowledge of the geographic location of one or more reference stations, which is used to compute corrections to GPS ranging measurements or resultant positions. These differential corrections are then transmitted to

GPS users, who apply the corrections to their received GPS signals or computed position. For a civil user of SPS, differential corrections can improve navigation accuracy from 100 meters (2 drms) to better than 7 meters (2 drms). A DGPS reference station is fixed at a geodetically surveyed position. From this position, the reference station typically tracks all satellites in view and computes corrections based on its measurements and geodetic position. These corrections are then broadcast to GPS users to improve their navigation solution. A well-developed methods of handling this is by computing pseudorange corrections for each satellite, which are then broadcast to the user and applied to the user's pseudorange measurements before the GPS position is calculated by the receiver, resulting in a highly accurate navigation solution.

The commonly used method is an all-in-view receiver at the reference site that receives signals from all visible satellites and measures the pseudorange to each. Since the satellite signal contains information on the satellite orbits and the reference receiver knows its position, the true range to each satellite can be calculated. By comparing the calculated range and the measured pseudorange, a correction term can be determined for each satellite. The corrections are broadcast and applied to the satellite measurements at each user's location. This method provides the best navigation solution for the user and is the preferred method. It is the method being employed by the USCG Maritime DGPS Service, the Nationwide DGPS (NDGPS) service, and the FAA LAAS.

The above method is being incorporated in the FAA's WAAS for GPS. In this system, a network of GPS reference/measurement stations at surveyed locations collects dual-frequency measurements of GPS pseudorange and pseudorange rate for all spacecraft in view, along with local meteorological conditions. These data can be processed to yield highly accurate ephemeris, ionospheric and tropospheric calibration maps, and DGPS corrections for the broadcast spacecraft ephemeris and clock offsets (including the effects of Selective Availability (SA)). In the WAAS, these GPS corrections and system integrity messages will be relayed to civil users via a dedicated package on geostationary satellites. This relay technique will also support the delivery of an additional ranging signal, thereby increasing overall navigation system availability.

Non-navigation users of GPS who require accuracy within a few centimeters accuracy or employ post processing to achieve accuracies within a few decimeters to a few meters, often employ augmentation somewhat differently from navigation users. For post processing applications using C/A code range, the actual observations from a reference station (rather than correctors) are provided to users. The users then compute correctors in their reduction software. Surveyors and other users who need sub-centimeter to a few centimeter accuracy in positioning from post-processing use two-frequency (L1 and L2) carrier phase observations from reference stations, rather than range data. The CORS system is designed to meet the needs of both of the above types of these users.

Real-time carrier phase differential positioning is increasingly employed by non-navigation users. Currently, this requires a GPS reference station within a few tens of kilometers of a user. In many cases, users are implementing their own reference stations, which they operate only for the duration of a specific project. Permanent reference stations to support real-time carrier phase positioning by multiple users are currently provided in the U.S. primarily by private industry. Some state and local government groups are moving toward providing such reference stations. Other countries are establishing nationwide, real-time, carrier phase reference station networks at the national government level.

With the advent of commercially available combined GPS/GLONASS receivers, non-navigation users will begin to augment GPS with reference stations that provide differential GPS and GLONASS. This will occur most rapidly where users operate in locations such as urban canyons and heavily forested areas where sufficient numbers of GPS satellites are not always in view to adequately support positioning.

A worldwide network of GPS reference stations is needed for geodetic reference frame, geophysical, and meteorological applications that require carrier phase data to achieve centimeter level accuracy on a regional to global basis. Such a network is currently operated by the IGS and provides the required centimeter-accuracy reference frame and sub-decimeter orbits. At present, this worldwide IGS reference network supports only post-processing applications. However, the IGS is moving toward near-real-time to real-time provision of information to support such applications as seismic monitoring and inclusion of water vapor information into short term weather prediction. Because this near-real-time and real-time information would be used by fixed facilities rather than moving platforms, it may be provided to users by telephone or similar communications links rather than by broadcast.

C.2.2.1 Maritime DGPS

Figure C-1 shows the maritime DGPS architecture using pseudorange corrections. The reference station's and other mariner's pseudorange calculations are strongly correlated. Pseudorange corrections computed by the reference station, when transmitted to the mariner in a timely manner, can be directly applied to the mariner's pseudorange computation to dramatically increase the resultant accuracy of the pseudorange measurement before it is applied within the mariner's navigation solution.

A. Signal Characteristics

The datalinks for DGPS corrections are broadcast sites transmitting between 285 and 325 kHz using MSK modulation. Real-time differential GPS corrections are provided in the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) format and broadcast to all users capable of receiving the signals. The Maritime DGPS Service operated by the USCG does not use data encryption. The characteristics of the Maritime DGPS Service are summarized in Table C-2.

B. Accuracy

The predictable accuracy of the Maritime DGPS Service within all established coverage areas is better than 10 meters (2 drms). The Maritime DGPS Service accuracy at each broadcast site is carefully controlled and is typically better than 1 meter. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the

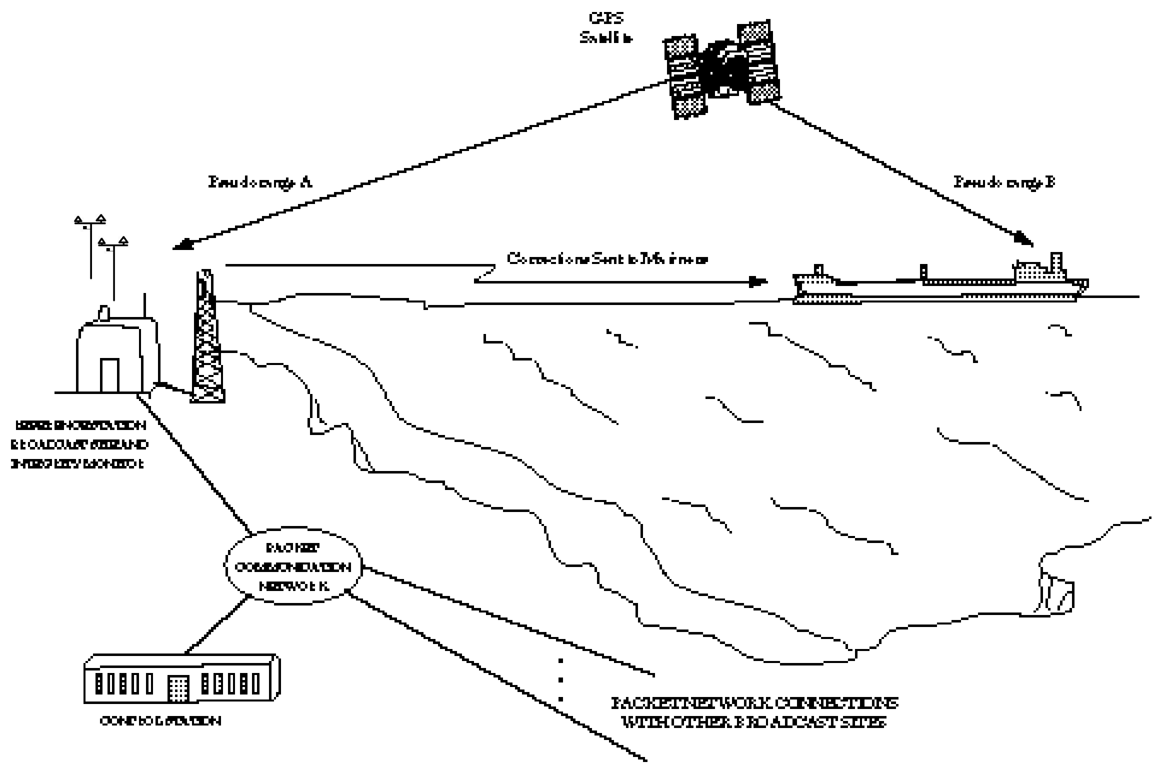

Figure C-1. Maritime DGPS Navigation Service

Table C-2. Maritime DGPS Service Characteristics (Signal-in-Space)

ACCURACY (2drms)	AVAILABILITY (%)	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL	INTEGRITY
<10 meters	99.9 selected areas 99.7 all other areas	U.S. coastal areas, selected areas of HI, AK, PR and major inland rivers	< 500 outages/1,000,000 hours	1-20 per second	3D	Unlimited	None	On-site integrity monitor and 24-hour DGPS control center

SYSTEM DESCRIPTION: The Maritime DGPS Service is a medium frequency beacon-based augmentation to GPS. The Maritime DGPS Service operated by the USCG consists of two control stations and more than 55 remote broadcast sites. The DGPS service broadcasts correction signals on marine radiobeacon frequencies to improve accuracy and integrity of the Global Positioning System.

broadcast site. Accuracy is further degraded by computational and other uncertainties in user equipment and the ability of user equipment to compensate for other error sources such as multipath and propagation distortions. A broadcast site accuracy of 1 meter should allow typical user equipment to achieve the stated 10-meter accuracy in all established coverage areas when the various factors that degrade accuracy are considered. High-end user equipment may achieve accuracies better than 3 meters by compensating for the various degrading factors.

C. Availability

Availability will be 99.9 percent in selected waterways with more stringent VTS requirements and at least 99.7 percent in other parts of the coverage area.

D. Coverage

Figure C-2 shows the approximate coverage of the Maritime DGPS Service operated by USCG. In accordance with the USCG's DGPS Broadcast Standard (COMDTINST M16577.1), the Maritime DGPS Service is designed to provide complete coastal DGPS coverage (to a minimum range of 20 nm from shore) of the continental U.S., selected portions of Hawaii, Alaska, and Puerto Rico, and inland coverage of the major inland rivers.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation.

F. Fix Rate

USCG DGPS Broadcast sites transmit a set of data every 2.5 seconds or better. Each set of data points includes both pseudorange and range rate corrections that permit a virtually continuous position update, but the need for receiver processing results in typical user fix rates of 1-20 per second.

G. Fix Dimensions

Through the application of pseudorange corrections, maritime DGPS provides three-dimensional positioning.

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

Integrity of the Maritime DGPS Service operated by the USCG is provided through an integrity monitor at each broadcast site. Each broadcast site is remotely monitored and controlled 24 hours a day from a DGPS control center. Users will be notified of an out-of-tolerance condition within 6 seconds.

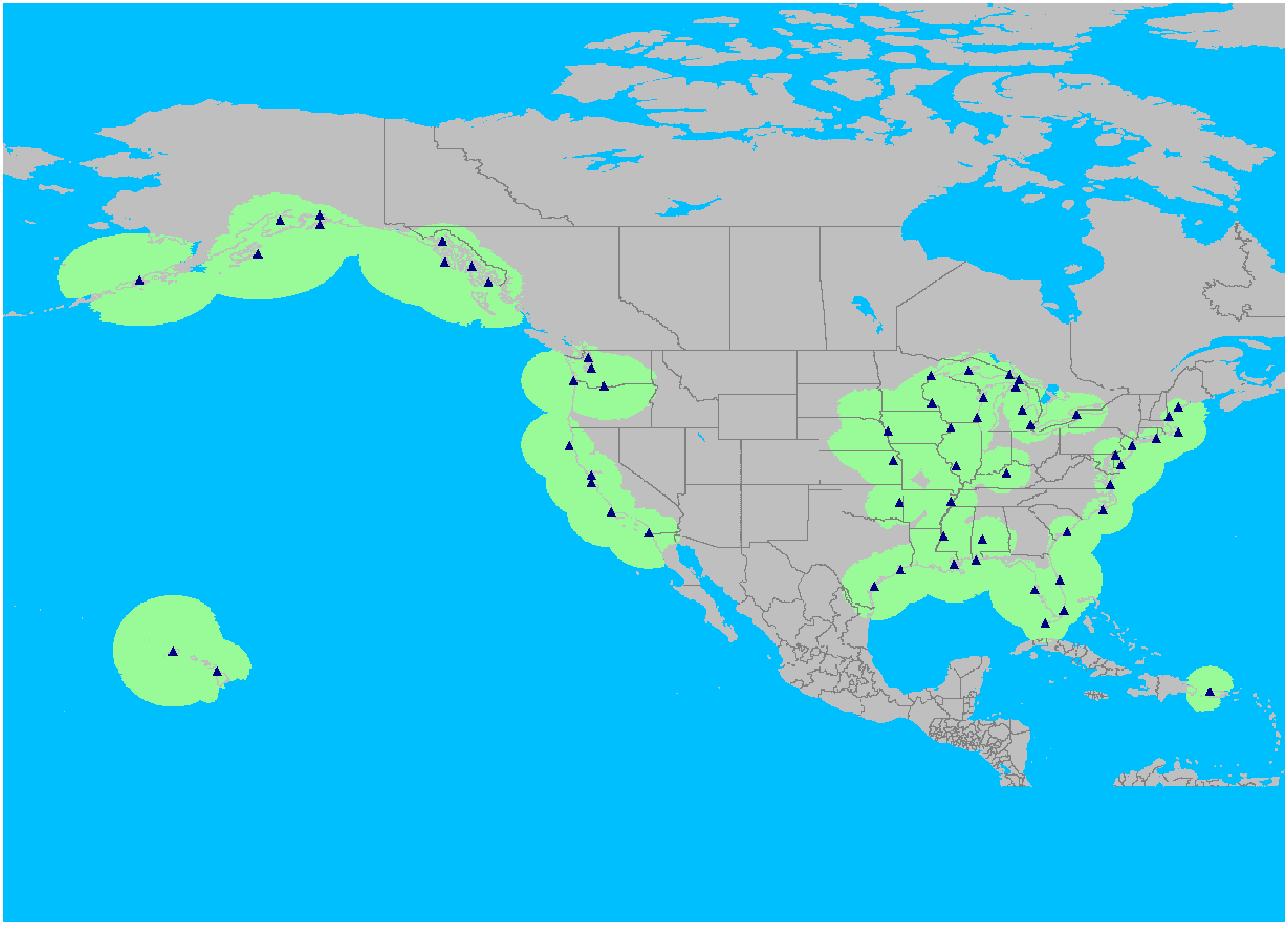

Figure C-2. U.S. Maritime DGPS Service Coverage

In addition to providing a highly accurate navigation signal, maritime DGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS. With the design of the ground segment of GPS, a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the Master Control Station or before users can be warned not to use the signal. Through its use of continuous, real-time messages, the Maritime DGPS Service can often extend the use of unhealthy GPS satellites by providing accurate corrections, or will direct the navigator to ignore an erroneous GPS signal.

C.2.2.2 Nationwide DGPS

The Nationwide DGPS (NDGPS) is based on the architecture of the Maritime DGPS Service. Figure C-3 shows the NDGPS architecture using pseudo-range corrections. Figure C-3 and the following discussion describe the characteristics of the NDGPS system.

A. Signal Characteristics

The datalinks for DGPS corrections are broadcast sites transmitting between 285 and 325 kHz using MSK modulation. Real-time differential GPS corrections are provided in the Radio Technical Commission for Maritime Services Special Committee 104 (RTCM SC-104) format and broadcast to all users capable of receiving the signals. The NDGPS does not use data encryption.

B. Accuracy

The predictable accuracy of the NDGPS Service within all established coverage areas is better then 10 meters (2 drms). NDGPS accuracy at each broadcast site is carefully controlled and is typically better than 1 meter. Achievable accuracy degrades at an approximate rate of 1 meter for each 150 km distance from the broadcast site. Accuracy is further degraded by computational and other uncertainties in user equipment and the ability of user equipment to compensate for other error sources such as multipath and propagation distortions. A broadcast site accuracy of 1 meter should allow typical user equipment to achieve the stated 10-meter accuracy in all established coverage areas when the various factors that degrade accuracy are considered. High-end user equipment may achieve accuracies better than 3 meters by compensating for the various degrading factors.

C. Availability

Availability will be 99.9 percent for dual coverage areas and 99.7 percent for single coverage areas. Availability is calculated on a per site per month basis, generally discounting GPS anomalies.

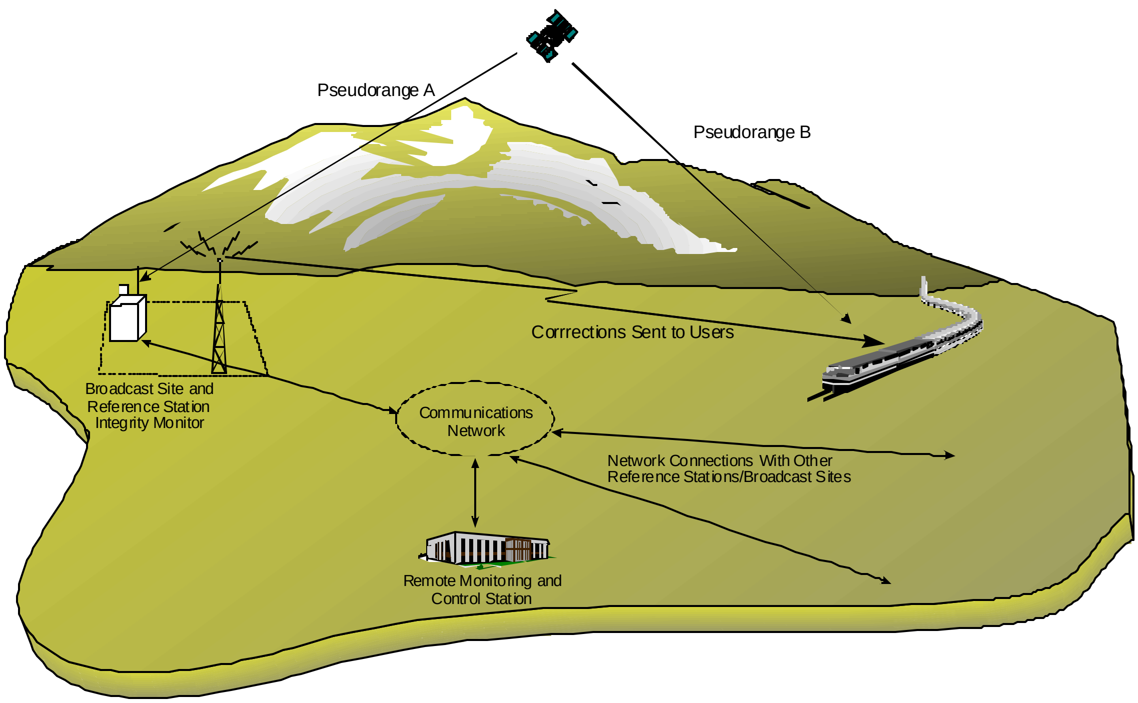

Figure C-3. NDGPS Navigation Service

D. Coverage

Figure C-4 shows the approximate locations of the NDGPS broadcast sites. Current plans envision providing dual coverage in the continental U.S. and in the transportation corridors in Alaska with single coverage in other areas.

E. Reliability

The number of outages per site will be less than 500 in one million hours of operation.

F. Fix Rate

USCG DGPS Broadcast sites transmit a set of data points every 2.5 seconds or better. Each set of data points includes both pseudorange and range rate corrections that permit virtually continuous position update, but the need for receiver processing results in typical user fix rates of 1-20 per second.

G. Fix Dimensions

Through the application of pseudorange corrections, maritime DGPS improves the accuracy of GPS three-dimensional positioning and velocity.

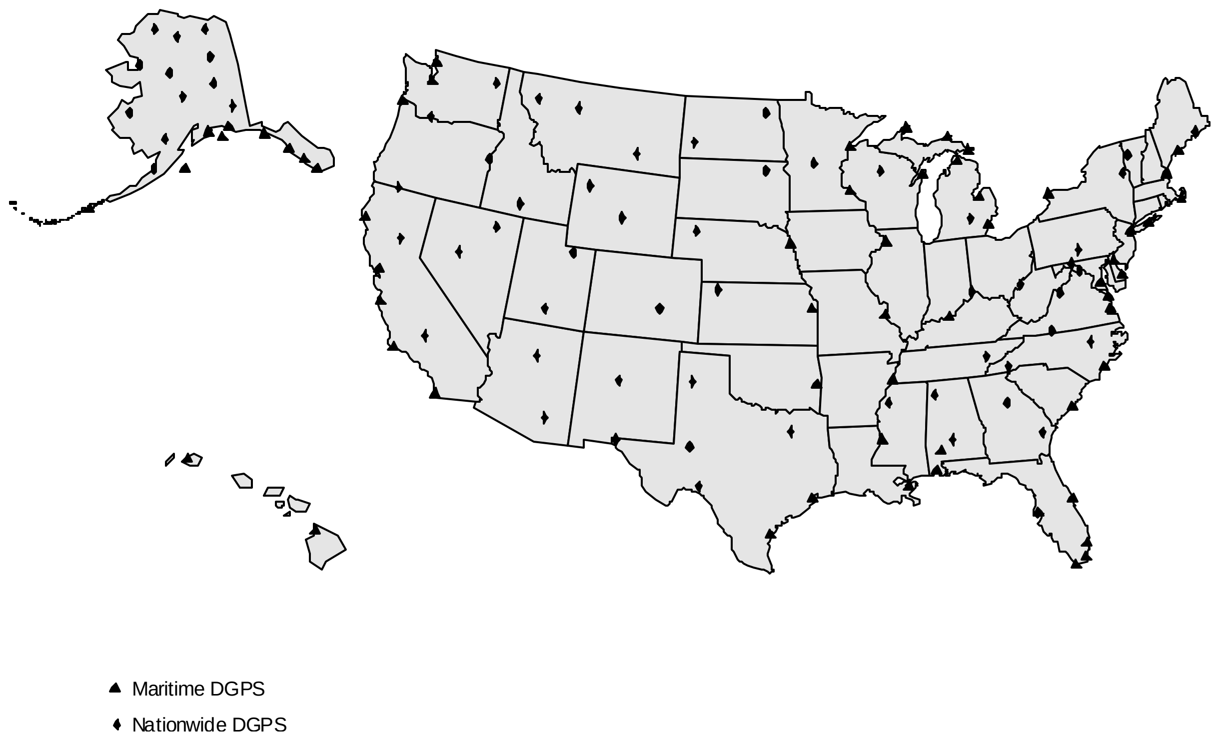

Figure C-4. Planned NDGPS Broadcast Sites

H. System Capacity

Unlimited.

I. Ambiguity

None.

J. Integrity

NDGPS system integrity is provided through an on-site integrity monitor and 24-hour operations at a NDGPS control center. Users will be notified of an out-of-tolerance condition within 6 seconds.

In addition to proving a highly accurate navigation signal, NDGPS also provides a continuous integrity check on satellite health. System integrity is a real concern with GPS. With the design of the ground segment of GPS, a satellite can be transmitting an unhealthy signal for 2 to 6 hours before it can be detected and corrected by the Master Control Station or before users can be warned not to use the signal. Through its use of continuous, real-time messages, the NDGPS system can often extend the use of unhealthy GPS satellites by providing accurate corrections, or will direct the navigator to ignore an erroneous GPS signal.

C.2.2.3 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS will be a safety-critical system consisting of the equipment and software that augments the DOD-provided GPS Standard Positioning Service (see Figure C-5). It will provide a signal-in-space to WAAS users with the specific goal of supporting aviation navigation for the en route through Category I precision approach phases of flight. The signal-in-space will provide three services: (1) integrity data on GPS and GEO satellites, (2) wide area differential corrections for GPS satellites, and (3) an additional ranging capability.

The GPS satellites' data are to be received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are forwarded to data processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GEO satellite navigation parameters. This information is to be sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to GEO satellites. These GEO satellites will then downlink these data on the GPS Link I (LI) frequency with a modulation similar to that used by GPS.

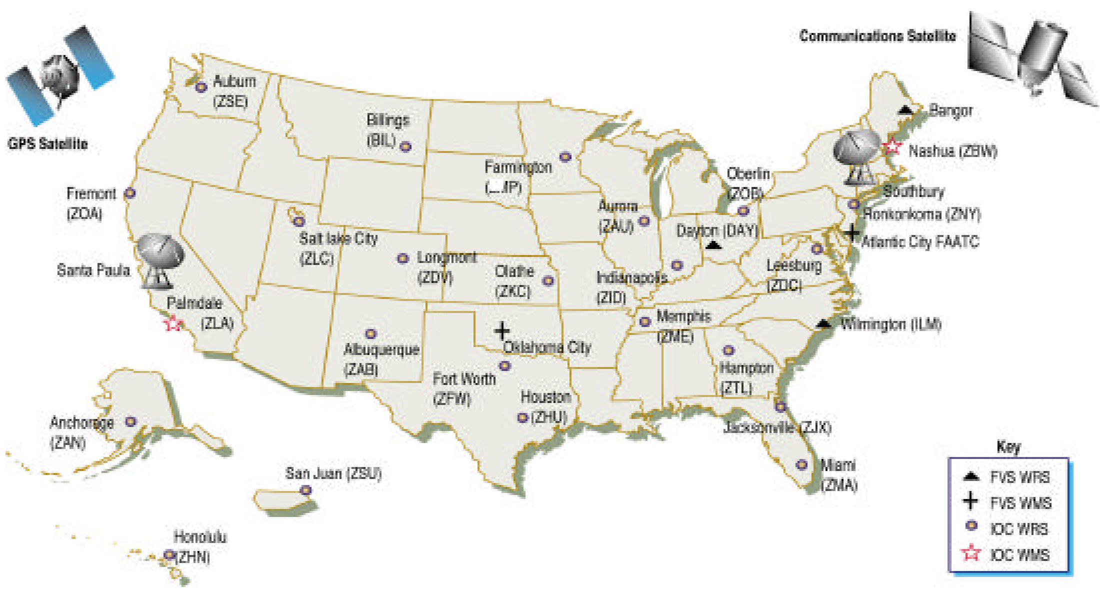

Figure C-5. WAAS Architecture

In addition to providing GPS integrity, the WAAS will verify its own integrity and take any necessary action to ensure that the system meets the WAAS performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA Airway Facilities NAS personnel.

The WAAS user receiver will process: (1) the integrity data to ensure that the satellites being used are providing in-tolerance navigation data, (2) the differential correction and ionospheric information data to improve the accuracy of the user's position solution, and (3) the ranging data from one or more of the GEO satellites for position determination to improve availability and continuity. The WAAS user receivers are not considered part of the WAAS.

A. Signal Characteristics

The WAAS will collect raw WAAS GEO and GPS data from all GPS and WAAS GEO satellites that support the navigation service.

WAAS ground equipment will develop messages on ranging signals and signal quality parameters of the GPS and GEO satellites. GEO satellites will broadcast the WAAS messages to the users and provide ranging sources. The signals broadcast via the WAAS GEOs to the WAAS users are designed to require minimal standard GPS receiver hardware modifications.

The GPS LI frequency and GPS-type modulation, including a C/A PRN code, will be used for WAAS data transmission. In addition, the code phase timing will be synchronized to GPS time to provide a ranging capability.

B. Accuracy

Accuracies for the WAAS are currently based on aviation requirements. For the en route through nonprecision approach phases of flight, a horizontal accuracy of 100 meters 95 percent of the time is guaranteed with the requisite availability and integrity levels to support operations in the NAS. For the Category I precision approach phase of flight, horizontal and vertical accuracies are guaranteed at 7.6 meters 95 percent of the time.

C. Availability

The WAAS availability for the en route through nonprecision approach phases of flight is at least 0.99999. For the precision approach phase of flight, the availability is at least 0.999.

D. Coverage

The WAAS full service volume is defined from the Category I decision height up to 100,000 feet for the airspace of the 48 contiguous states, Hawaii, Puerto Rico, and Alaska (except for the Alaskan peninsula west of longitude 160 degrees West or outside of the GEO satellite broadcast area).

E. Reliability

The WAAS will provide sufficient reliability and redundancy to meet the overall NAS requirements with no single point of failure. The overall reliability of the WAAS signal-in-space will approach 100 percent.

F. Fix Rate

This system provides a virtually continuous position update.

G. Fix Dimensions

The WAAS provides three-dimensional position fixing and highly-accurate timing information.

H. System Capacity

The user capacity is unlimited.

I. Ambiguity

The system provides no ambiguity of position fixing information.

J. Integrity

Integrity augmentation of the GPS SPS by the WAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance levels for the integrity augmentation are the levels necessary so that GPS/WAAS can be used for all phases of flight.

Integrity for the WAAS is specified by three parameters: probability of hazardously misleading information (PHMI), time to alarm, and the alarm limit. For the en route through nonprecision approach phases of flight, the performance values are:

PHMI	10^{-7} per hour
Time to Alarm	8 seconds
Alarm Limit	Protection limits specified for each phase of flight

For the precision approach phase of flight, integrity performance values are:

PHMI	4×10^{-8} per approach
Time to Alarm	5.2 seconds
Alarm Limit	As required for Category I operation

The WAAS will provide the information such that the user equipment can determine the integrity to these levels.

C.2.2.4 GPS Local Area Augmentation System (LAAS)

The LAAS will be a safety critical precision navigation and landing system consisting of equipment to augment the DOD-provided GPS Standard Positioning Service with differential GPS pseudorange corrections. It will provide a signal-in-space to LAAS-equipped users with the specific goal of supporting terminal area navigation through Category III precision approach, including autoland. The LAAS signal-in-space will provide; (1) local area differential corrections for GPS PRNs, WAAS/Space-Based Augmentation System (SBAS), GEOs, and Airport Pseudolites (APLs), (2) the associated integrity parameters, and (3) precision approach final approach segment description path points.

The LAAS will utilize multiple GPS reference receivers and their associated antennas, all located within the airport boundary, to receive and decode the GPS, WAAS GEO, and APL range measurements and navigation data. Data from the individual reference receivers are processed by Signal Quality Monitoring, Navigation Data Quality Monitoring, Measurement Quality Monitoring, and Integrity Monitoring algorithms. An averaging technique is used to provide optimal differential range corrections for each measurement and possessing the requisite fidelity to meet accuracy, integrity, continuity of service, and availability criteria.

The individual differential range measurement corrections, integrity parameters and final approach segment path points descriptions for each runway end being served are broadcast to aircraft operating in the local terminal area (nominally 20 nm) via a LAAS VHF data broadcast transmission.

Airborne LAAS capable receivers receive and apply the differential correction to their own satellite and pseudolite pseudorange measurements and assess error parameters against maximum allowable error bounds for the category of approach being performed.

A. Signal Characteristics

The LAAS will collect raw GPS, WAAS GEO, and APL range data from all available range sources that support the navigation service.

The LAAS ground facility will generate differential correction messages as well as pseudorange correction error parameters for each of the GPS, WAAS GEO and APL ranging measurements. The LAAS VHF data broadcast transmitter will then broadcast the LAAS DGPS data to LAAS users.

The GPS L1 frequency and a GPS-like modulation including a wideband PRN code will be used for the LAAS APL availability augmentation transmission. The VHF ARNS band, 108-117.975 MHz, is planned for the LAAS VHF data broadcast.

B. Accuracy

Accuracy for the LAAS has been derived from the aviation accuracy requirements of the ILS. For Category I precision approach the lateral accuracy is 16.0 meters, 95 percent.

The LAAS Category I vertical accuracy is 4.0 meters, 95 percent (per the RTCA LAAS MASPS).

C. Availability

The availability of the LAAS is airport dependent, but ranges between 0.999 - 0.99999 (per the draft FAA LAAS specification).

D. Coverage

The LAAS full service volume is defined as:

Vertically: Beginning at the runway datum point out to 20 nm above 0.9 degrees and below 10,000 feet.

Horizontally: 450 ft. either side of the runway beginning at the RDP and projecting out ± 35 degrees either side of the approach path out to 20 nm (per the draft FAA LAAS spec.).

E. Reliability

Reliability figures have not been developed.

F. Fix Rate

The LAAS broadcast fix rate is 2Hz. The fix rate from the airborne receiver is at least 5Hz.

G. Fix Dimensions

The LAAS provides three-dimensional position fixing and highly accurate timing information.

H. System Capacity

There is no limit on the LAAS System Capacity.

I. Ambiguity

There is no ambiguity of position associated with the LAAS.

J. Integrity

Assurance of position integrity of the GPS SPS by the LAAS is a required capability that is both an operational characteristic and a technical characteristic. The required system performance is defined for each of the categories of approach. Integrity is specified for two separate parameters: PHMI and Time to Alarm.

Category I		Category II/III	
PHMI	$1x10^{-7}$	PHMI	$1x10^{-9}$
Time to Alarm	6 seconds	Time to Alarm	2 seconds

C.2.3 Loran-C

Loran-C was developed to provide DOD with a radionavigation capability having longer range and much greater accuracy than its predecessor, Loran-A. It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. Loran-C is also certified as an en route supplemental navigation aid for civil aviation.

A. Signal Characteristics

Loran-C is a pulsed, hyperbolic system operating in the 90 to 110 kHz frequency band. The system is based upon measurement of the difference in time of arrival of pulses of radio frequency (RF) energy radiated by a chain of synchronized transmitters that are separated by hundreds of miles. The measurements of time difference (TD) are made by a receiver which achieves high accuracy by comparing a zero crossing of a specified RF cycle within the pulses transmitted by master and secondary stations within a chain. Making this signal comparison early in the ground wave pulse assures that the measurement is made before the arrival of the corresponding sky waves. Precise control over the pulse shape ensures that the proper comparison point can be identified by the receiver. To aid in preventing sky waves from affecting TD measurements, the phase of the 100 kHz carrier of some of the pulses is changed in a predetermined pattern. Envelope matching of the signals is also possible but cannot provide the advantage of cycle comparison in obtaining the full system accuracy. The characteristics of Loran-C are summarized in Table C-3.

Table C-3. Loran-C System Characteristics (Signal-in-Space)

ACCURACY (2 drms)					FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	AVAILABILITY	COVERAGE	RELIABILITY	RATE	DIMENSIONS	CAPACITY	POTENTIAL
0.25nm (460m)	60-300 ft. (18-90m)	99.7%	U.S. coastal areas, continental U.S., selected overseas areas	99.7%*	10-20 fix/sec.	2D + Time	Unlimited	Yes, easily resolved

* *Triad reliability.*

SYSTEM DESCRIPTION: Loran-C is a Low Frequency (LF) 100 kHz hyperbolic radionavigation system. The receiver computes lines of position (LOP) based on the time of arrival difference between two time-synchronized transmitting stations of a chain. Three stations are required (master and two secondaries) to obtain a position fix in the normal mode of operation. Loran-C can be used in the Rho-Rho mode and accurate position data can be obtained with only two stations. Rho-Rho requires that the user platform have a precise clock.

B. Accuracy

Within the published coverage area, Loran-C provides the user who employs an adequate receiver with predictable accuracy of 0.25 nm (2 drms) or better. The repeatable accuracy of Loran-C is usually between 18 and 90 meters. Accuracy is dependent upon the Geometric Dilution of Precision (GDOP) factors at the user's location within the coverage area.

Loran-C navigation is predominantly accomplished using the ground wave signal. Sky wave navigation is feasible, but with considerable loss in accuracy. Ground waves and to some degree sky waves may be used for measuring time and time intervals. Loran-C was originally designed to be a hyperbolic navigation system. However, with the advent of the highly stable frequency standards, Loran-C can also be used in the range-range (rho-rho) mode of navigation. This is accomplished by a comparison of the received signal phase to a known time reference to determine propagation time and, therefore, range from the stations. It can be used in situations where the user is within reception range of individual stations, but beyond the hyperbolic coverage area. Because the position solution of GPS provides precise time, the interpretable use of rho-rho Loran-C with GPS appears to have merit.

By monitoring Loran-C signals at a fixed site, the receiver TD can be compared with a computed TD for the known location of the site. A correction for the area can then be broadcast to users. This technique (called differential Loran-C), whereby real-time corrections are applied to Loran-C TD readings, provides improved accuracy. Although this can improve Loran-C's absolute accuracy features, no investment in this approach to enhancing Loran-C's performance is anticipated by the Federal Government.

Loran-C receivers are available at a relatively low cost and achieve the 0.25 nm (2 drms) accuracy that Loran-C provides at the limits of the coverage area. A modern Loran-C receiver automatically acquires and tracks the Loran-C signal and is useful to the limits of the specified Loran-C coverage areas.

C. Availability

The Loran-C transmitting equipment is very reliable. Redundant transmitting equipment is used to reduce system downtime. Loran-C transmitting station signal availability is greater than 99.9 percent, providing 99.7 percent triad availability.

D. Coverage

The Loran-C system has been expanded over the years to meet the requirements for coverage of the U.S. coastal waters and the conterminous 48 states, the Great Lakes, the Gulf of Alaska, the Aleutians, and into the Bering Sea. The limit of coverage in a given area is determined by the lesser of: a) predictable accuracy limits of 0.25 nm; or b) signal-to-noise ratio limit of 1:3 SNR. Current Loran-C coverage is shown in Figure C-6.

Expansion of the Loran-C system into the Caribbean Sea and the North Slope of Alaska has been investigated.

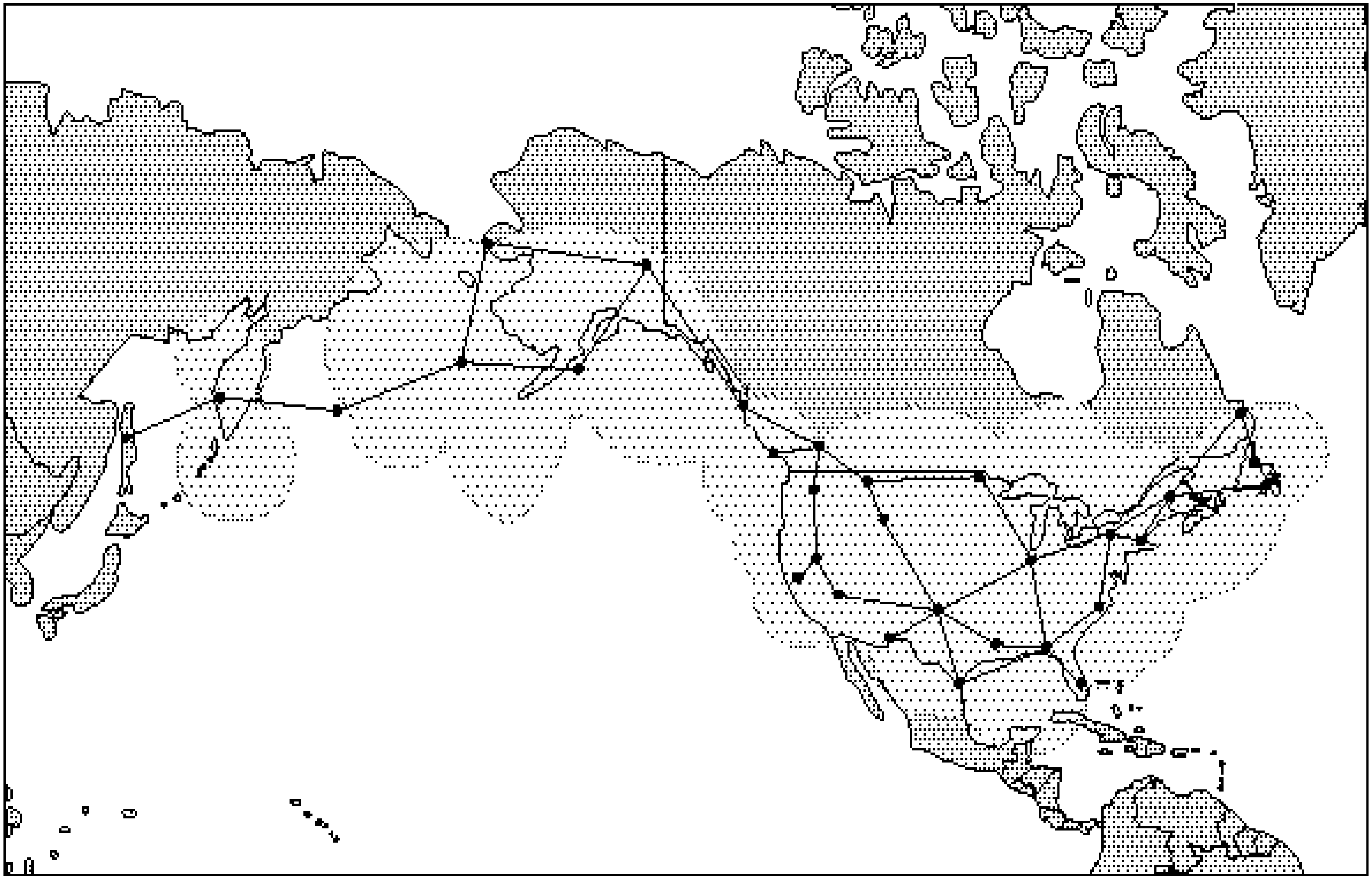

Figure C-6. Coverage Provided by U.S. or Supported Loran-C Stations

E. Reliability

Loran-C stations are constantly monitored. Stations that exceed the system tolerance are "blinked." Blink is the on-off pattern of the first two pulses of the secondary signal indicating that a baseline is unusable. System tolerance within the U.S. is $\pm$100 nanoseconds of the calibrated control value. Individual station reliability normally exceeds 99.9 percent, resulting in triad availability exceeding 99.7 percent.

F. Fix Rate

The fix rate available from Loran-C ranges from 10 to 20 fixes per second, based on the Group Repetition Interval. Receiver processing in noise results in typically 1 fix per second.

G. Fix Dimensions

Loran-C provides a two-dimensional fix plus time.

H. System Capacity

An unlimited number of receivers may use Loran-C simultaneously.

I. Ambiguity

As with all hyperbolic systems, theoretically, the LOPs may cross at more than one position on the earth. However, because of the design of the coverage area, the ambiguous fix is at a great distance from the desired fix and is easily resolved.

J. Integrity

Loran-C signals are constantly monitored to detect signal abnormalities that would render the system unusable for navigation purposes. The secondary stations "blink" to notify the user that a master-secondary pair is unusable. Blink is manually initiated immediately upon detection of an abnormality. The USCG and the FAA are installing automatic blink equipment and a concept of operations based on factors consistent with aviation use. Where automatic blink equipment is installed in the NAS, secondary blink is automatically initiated within ten seconds of a timing abnormality exceeding $\pm$ 500 nanoseconds, and in the case of a Master station, the signal will be taken off-air until the problem is corrected and all secondaries are blinking.

C.2.4 VOR, VOR/DME, and TACAN

The three systems that provide the basic guidance for en route air navigation in the United States are VOR, DME, and TACAN. Information provided to the aircraft pilot by VOR is the azimuth relative to the VOR ground station. DME provides a measurement of distance from the aircraft to the DME ground station. In most cases, VOR and DME are collocated as a VOR/DME facility. TACAN provides both azimuth and distance information and is used primarily by military aircraft. When TACAN is collocated with VOR, it is a VORTAC facility. DME and the distance measuring function of TACAN are functionally the same.

I. VOR

A. Signal Characteristics

The signal characteristics of VOR are summarized in Table C-4. VORs are assigned frequencies in the 108 to 117.975 MHz ARNS frequency band, separated by 50 kHz. A VOR transmits two 30 Hz modulations resulting in a relative electrical phase angle equal to the azimuth angle of the receiving aircraft. A cardioid field pattern is produced in the horizontal plane and rotates at 30 Hz. A nondirectional (circular) 30 Hz pattern is also transmitted during the same time in all directions and is called the reference phase signal.

Table C-4. VOR and VOR/DME System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)						FIX	FIX	SYSTEM	AMBIGUITY
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	RATE	DIMENSIONS	CAPACITY	POTENTIAL
VOR: 90m (±1.4°)*	23m (±0.35°)**	--	Approaches 100%	Line of Sight	Approaches 100%	Continuous	Heading in degrees or angle off course	Unlimited	None
DME: 185m (±0.1nm)	185m (±0.1nm)	--					Slant range (nm)	100 users per site, full service	

* *The flight check of published procedures for the VOR signal is ± 1.4°. The ground monitor turns the system off if the signal exceeds ± 1.0°. The cross-track error used in the chart is for ± 1.4° at 2nm from the VOR site. However, some uses of VOR are overhead and/or 1/2nm from the VOR.*

** *Test data shows that 99.94% of the time the error is less than ± 0.35°. These values are for ± 0.35° at 2nm from the VOR.*

SYSTEM DESCRIPTION: VOR provides aircraft with bearing information relative to the VOR signal and magnetic north. The system is used for landing, terminal, and en route guidance. VOR transmitters operate in the VHF frequency range. DME provides a measurement of distance from the aircraft to the DME ground station. DME operates in the UHF frequency range.

The variable phase pattern changes phase in direct relationship to azimuth. The reference phase is frequency modulated while the variable phase is amplitude modulated. The receiver detects these two signals and computes the azimuth from the relative phase difference. For difficult siting situations, a system using the Doppler effect was developed and uses 50 instead of four antennas for the variable phase. The same avionics works with either type ground station.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are approximately ±1.4 degrees. The addition of course selection, receiver and flight technical errors, when combined using root-sum-squared (RSS) techniques, is calculated to be ±4.5 degrees.

- Relative - Although some course bending could influence position readings between aircraft, the major relative error consists of the course selection, receiver and flight technical components. When combined using RSS techniques, the value is approximately ±4.3 degrees. The VOR ground station relative error is ±0.35 degrees.
- Repeatable - The major error components of the ground system and receiver will not vary appreciably in the short term. Therefore, the repeatable error will consist mainly of the flight technical error (the pilots' ability to fly the system) which is ±2.3 degrees.

C. Availability

Because VOR coverage is overlapped by adjacent stations, the availability is considered to approach 100 percent for new solid state equipment.

D. Coverage

VOR has line-of-sight limitations that could limit ground coverage to 30 miles or less. At altitudes above 5,000 feet, the range is approximately 100 nm, and above 20,000 feet, the range will approach 200 nm. These stations radiate approximately 200 watts. Terminal VOR stations are rated at approximately 50 watts and are only intended for use within the terminal areas. Actual VOR coverage information is contained in FAA Order 1010.55C.

E. Reliability

Due to advanced solid-state construction and the use of remote maintenance monitoring techniques, the reliability of solid state VOR approaches 100 percent.

F. Fix Rate

This system allows an essentially continuous update of deviation from a selected course based on internal operations at a 30-update-per-second rate. Initialization is less than one minute after turn-on and will vary as to receiver design.

G. Fix Dimensions

The system shows magnetic bearing to a VOR station and deviation from a selected course, in degrees.

H. System Capacity

The capacity of a VOR station is unlimited.

I. Ambiguity

There is no ambiguity possible for a VOR station.

J. Integrity

VOR provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

II. DME

A. Signal Characteristics

The signal characteristics of DME are summarized in Table C-4. The interrogator in the aircraft generates a pulsed signal (interrogation) which, when of the correct frequency and pulse spacings, is accepted by the transponder. In turn, the transponder generates pulsed signals (replies) that are sent back and accepted by the interrogator's tracking circuitry. Distance is then computed by measuring the total round trip time of the interrogation and its reply. The operation of DME is thus accomplished by paired pulse signals and the recognition of desired pulse spacings accomplished by the use of a decoder. The transponder must reply to all interrogators. The interrogator must measure elapsed time between interrogation and reply pulse pairs and translate this to distance. All signals are vertically polarized. These systems are assigned in the 962-1215 MHz ARNS frequency band with a separation of 1 MHz.

The capability to use Y-channel service has been developed and implemented to a very limited extent (approximately 15 DMEs paired with localizers use the Y-channel frequencies). The term "Y-channel" refers to VOR frequency spacing. Normally, X-channel frequency spacing of 100 kHz is used. Y-channel frequencies are offset from the X-channel frequencies by 50 kHz. In addition, Y-channel DMEs are identified by a wider interrogation pulse-pair time spacing of 0.036 msec versus X-channel DMEs at 0.012 msec spacing. X- and Y-channel applications are presently limited to minimize user equipment changeovers.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±0.1 nm. The overall system error (airborne and ground RSS) is not greater than ±0.5 nm or 3 percent of the distance, whichever is greater.
- Relative - Although some errors could be introduced by reflections, the major relative error emanates from the receiver and flight technical error.
- Repeatable - Major error components of the ground system and receiver will not vary appreciably in the short term.

C. Availability

The availability of DME is considered to approach 100 percent, with positive indication when the system is out-of-tolerance.

D. Coverage

DME has a line-of-sight limitation, which limits ground coverage to 30 nm or less. At altitudes above 5,000 feet, the range will approach 100 nm. En route stations radiate at 1,000 watts. Terminal DMEs radiate 100 watts and are only intended for use in terminal areas. Because of facility placement, almost all of the airways have coverage and most of the CONUS have dual coverage, permitting DME/DME Area Navigation (RNAV).

E. Reliability

With the use of solid-state components and remote maintenance monitoring techniques, the reliability of the DME approaches 100 percent.

F. Fix Rate

The system essentially gives a continuous update of distance to the facility. Actual update rate varies with the design of airborne equipment and system loading, with typical rates of 10 per second.

G. Fix Dimensions

The system shows slant range to the DME station in nm.

H. System Capacity

For present traffic capacity 110 interrogators are considered reasonable. Future traffic capacity could be increased when necessary through reduced individual aircraft interrogation rates and removal of beacon capacity reply restrictions.

I. Ambiguity

There is no ambiguity in the DME system.

J. Integrity

DME provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

III. TACAN

A. Signal Characteristics

TACAN is a short-range UHF (962-1215 MHz ARNS band) radionavigation system designed primarily for military aircraft use. TACAN transmitters and responders provide the data necessary to determine magnetic bearing and distance from an aircraft to a selected station. TACAN stations in the U.S. are frequently collocated with VOR stations. These facilities are known as VORTACs. The signal characteristics of TACAN are summarized in Table C-5.

Table C-5. TACAN System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSIONS	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
PREDICTABLE	REPEATABLE	RELATIVE							
Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (± 63m at 3.75km)	Azimuth ±1° (±63m at 3.75km)	98%	Line of sight	99%	Continuous	Distance and bearing from station	110 for distance Unlimited in azimuth	No ambiguity in range Slight potential for ambiguity at multiples of 40°
DME: 185m (±0.1nm)	DME: 185m (±0.1nm)	DME: 185m (±0.1nm)							

SYSTEM DESCRIPTION : TACAN is a short-range UHF navigation system used by the military. The system provides range, bearing, and station identification. When TACAN is collocated with a VOR it is called a VORTAC facility.

B. Accuracy (2 sigma)

- Predictable - The ground station errors are less than ±1.0 degree for azimuth for the 135 Hz element and ±4.5 degrees for the 15 Hz element. Distance errors are the same as DME errors.
- Relative - The major relative errors emanate from course selection, receiver and flight technical error.
- Repeatable - Major error components of the ground station and receiver will not vary greatly in the short term. The repeatable error will consist mainly of the flight technical error.

C. Availability

A TACAN station can be expected to be available 98 percent of the time.

D. Coverage

TACAN has a line-of-sight limitation that limits ground coverage to 30 nm or less. At altitudes of 5,000 feet, the range will approach 100 nm; above 18,000 feet, the range approaches 200 nm. This coverage is based on a 5 kW station.

E. Reliability

A TACAN station can be expected to be reliable 98 percent of the time. Unreliable stations, as determined by remote monitors, are automatically removed from service.

F. Fix Rate

TACAN provides a continuous update of the deviation from a selected course. Initialization is less than one minute after turn on. Actual update rate varies with the design of airborne equipment and system loading.

G. Fix Dimensions

The system shows magnetic bearing, deviation in degrees, and distance to the TACAN station in nautical miles.

H. System Capacity

For distance information, 110 interrogators are considered reasonable for present traffic handling. Future traffic handling could be increased when necessary through reduced airborne interrogation rates and increased reply rates. Capacity for the azimuth function is unlimited.

I. Ambiguity

There is no ambiguity in the TACAN range information. There is a slight probability of azimuth ambiguity at multiples of 40 degrees.

J. Integrity

TACAN provides system integrity by removing a signal from use within ten seconds of an out-of-tolerance condition detected by an independent monitor.

C.2.5 ILS

ILS is a precision approach system normally consisting of a localizer facility, a glide slope facility, and associated VHF marker beacons. It provides vertical and horizontal navigation (guidance) information during the approach to landing at an airport runway.

At present, ILS is one of the primary worldwide, ICAO-approved, precision landing system. This system is presently adequate, but has limitations in siting, frequency allocation, cost, and performance. The characteristics of ILS are summarized in Table C-6.

A. Signal Characteristics

The localizer facility and antenna are typically located 1,000 feet beyond the stop end of the runway and provide a VHF (108 to 111.975 MHz ARNS band) signal. The glide slope facility is located approximately 1,000 feet from the approach end of the runway and provides a UHF (328.6 to 335.4 MHz ARNS band) signal. Marker beacons are located along an extension of the runway centerline and identify particular locations on the approach. Ordinarily, two 75

MHz beacons are included as part of the instrument landing system: an outer marker at the final approach fix (typically four to seven miles from the approach end of the runway) and a middle marker located 3,500 feet plus or minus 250 feet from the runway threshold. The middle marker is located so as to note impending visual acquisition of the runway in conditions of minimum visibility for Category I ILS approaches. An inner marker, located approximately 1,000 feet from the threshold, is normally associated with Category II and III ILS approaches.

Table C-6. ILS Characteristics (Signal-in-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)			AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE*	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
CATEGORY	AZIMUTH	ELEVATION							
1	± 9.1	± 3.0	Approaches 99%	Normal limits from center of localizer ±10° out to 18nm and ±35° out to 10nm	98.6% with positive indication when the system is out of tolerance	Continuous	Heading and deviation in degrees	Limited only by aircraft separation requirements	None
2	± 4.6	± 1.4							
3	± 4.1	± 0.4							

* *Signal availability in the coverage volume.*

SYSTEM DESCRIPTION : The Instrument Landing System (ILS) is a precision approach system consisting of a localizer facility, a glide slope facility, and two or three VHF marker beacons. The VHF (108-111.975 MHz ARNS band) localizer facility provides accurate, single path horizontal guidance information. The UHF (328.6-335.4 MHz ARNS band) glide slope provides precise, single path, vertical guidance information to a landing aircraft.

B. Accuracy

For typical air carrier operations at a 10,000 foot runway, the course alignment (localizer) at threshold is maintained within ±25 feet. Course bends during the final segment of the approach do not exceed ±0.06 degrees (2 sigma). Glide slope course alignment is maintained within ±7.0 feet at 100 feet (2 sigma) elevation and glide path bends during the final segment of the approach do not exceed ±0.07 degrees (2 sigma).

C. Availability

To further improve the availability of service from ILS installations, vacuum tube equipment has been replaced with solid-state equipment. Service availability is now approaching 99 percent.

D. Coverage

Coverage for individual systems is as follows:

Localizer: $\pm 2^{o}$centered about runway centerline.

Glide Slope: Nominally 3^{o}above the horizontal.

Marker Beacons: $\pm 40^{o}$ (approximately) on minor axis (along approach path) $\pm 85^{o}$ (approximately) on major axis.

E. Reliability

ILS reliability is 98.6 percent. However, terrain and other factors may impose limitations upon the use of the ILS signal. Special account must be taken of terrain factors and dynamic factors such as taxiing aircraft that can cause multipath.

In some cases, to resolve ILS siting problems, use has been made of localizers with aperture antenna arrays and two frequency systems. In the case of the glide slope, use has been made of wide aperture, capture effect image arrays and single-frequency infrared arrays to provide service at difficult sites.

F. Fix Rate

The glide slope and localizer provide continuous fix information, although the user will receive position updates at a rate determined by receiver/display design (typically more than 5 updates per second). Marker beacons that provide an audible and visual indication to the pilot are sited at specific points along the approach path as indicated in Table C-7.

Table C-7. Aircraft Marker Beacons

MARKER DESIGNATION	TYPICAL DISTANCE TO THRESHOLD	AUDIBLE SIGNAL	LIGHT COLOR
Outer	4-7nm	Continuous dashes (2/sec)	Blue
Middle	3,250-3,750 ft	Continuous alternating (dot-dash)	Amber
Inner	1,000 ft	Continuous dots (6/sec)	White

G. Fix Dimensions

ILS provides both vertical and horizontal guidance with glide slope and localizer signals. At periodic intervals (passing over marker beacons) distance to threshold is obtained.

H. System Capacity

ILS has no capacity limitations except those imposed by aircraft separation requirements since aircraft must be in trail to use the system.

I. Ambiguity

Any potential ambiguities are resolved by imposing system limitations as described in Section C.2.5.E.

J. Integrity

ILS provides system integrity by removing a signal from use when an out-of-tolerance condition is detected by an integral monitor. The shutdown delay for each category is given below:

Shutdown Delay

	Localizer	**Glide Slope**
CAT I	<10 sec	<6 sec
CAT II	<5 sec	<2 sec
CAT III	<2 sec	<2 sec

C.2.6 MLS

MLS provides a common civil/military landing system to meet the full range of user operational requirements, as defined in the ICAO list of 38 operational requirements for precision approach and landing systems, to the year 2000 and beyond. It was originally intended to be a replacement for ILS, used by both civil and military aircraft, and the Ground Controlled Approach (GCA) system used primarily by military operators. However, augmented GPS systems are now envisioned to satisfy the majority of requirements originally earmarked for MLS. Accordingly, the FAA has terminated all R&D activity associated with MLS. The system characteristics of MLS are summarized in Table C-8.

Table C-8. MLS Characteristics (Signal-in-Space)

ACCURACY AT DECISION HEIGHT (Meters - 2 Sigma)										
CATEGORY	AZIMUTH	ELEVATION	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE*	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
1	± 9.1	± 3.0	Expected to approach 100%	± 40° from center line of runway out to 20nm in both directions*	Expected to approach 100%	6.5-39 fixes/sec depending on function	Heading and deviation in degrees Range in nm	Limited only by aircraft separation requirements	None
2	± 4.6	± 1.4							
3	± 4.1	± 0.4							

* *There are provisions for 360º out to 20nm.*

SYSTEM DESCRIPTION : The Microwave Landing System (MLS) is a precision landing system that will operate in the 5-5.25 GHz ARNS band. Ranging is provided by precision DME operating in 962-1215 MHz ARNS band.

A. Signal Characteristics

MLS transmits signals that enable airborne units to determine the precise azimuth angle, elevation angle, and range. The technique chosen for the angle function of the MLS is based upon Time-Referenced Scanning Beams (TRSB). All angle functions of MLS operate in the 5.00 to 5.25 GHz ARNS band. Ranging is provided by DME operating in the 962 - 1215 MHz ARNS band. An option is included in the signal format to permit a special purpose system to operate in the 15.4 to 15.7 GHz ARNS band.

B. Accuracy (2 sigma)

The azimuth accuracy is ±13.0 feet (+4.0m) at the runway threshold approach reference datum and the elevation accuracy is ±2.0 feet (+0.6m). The lower surface of the MLS beam crosses the threshold at 8 feet (2.4 meters) above the runway centerline. The flare guidance accuracy is ±1.2 feet throughout the touchdown zone and the DME accuracy is ±100 feet for the precision mode and ±1,600 feet for the nonprecision mode.

C. Availability

Equipment redundancy, as well as remote maintenance monitoring techniques, should allow the availability of this system to approach 100 percent.

D. Coverage

Current plans call for the installation of systems with azimuthal coverage of ±40^{o}on either side of the runway centerline, elevation coverage from 0^{o} to a minimum of 15^{o}over the azimuthal coverage area, and out to 20 nm. A few systems will have ±60^{o}azimuthal coverage. MLS signal format has the capability of providing coverage to the entire 360^{o} area but with less accuracy in the area outside the primary coverage area of +60^{o} of runway centerline. There will be simultaneous operations of ILS and MLS during the transition period.

E. Reliability

The MLS signals are generally less sensitive than ILS signals to the effects of snow, vegetation, terrain, structures, and taxiing aircraft. This allows the reliability of this system to approach 100 percent.

F. Fix Rate

Elevation angle is transmitted at 39 samples per second, azimuth angle at 13 samples per second, and back azimuth angle at 6.5 samples per second. Usually, the airborne receiver averages several data samples to provide fixes of 3 to 6 samples per second. A high rate azimuth angle function of 39 samples per second is available and is normally used where there is no need for flare elevation data.

G. Fix Dimensions

This system provides signals in all three dimensions and can provide time if aircraft are suitably equipped.

H. System Capacity

DME signals of this system are capacity limited; the system limits are approached when 110 aircraft are handled.

I. Ambiguity

No ambiguity is possible for the azimuth or elevation signals. Only a very small probability for ambiguity exists for the range signals and then only for multipath caused by moving reflectors.

J. Integrity

MLS integrity is provided by an integral monitor. The monitor shuts down the MLS within one second of an out-of-tolerance condition.

C.2.7 Aeronautical Radiobeacons

Radiobeacons are nondirectional radio transmitting stations that operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. An automatic direction finder (ADF) is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

The characteristics of aeronautical NDBs are summarized in Table C-9.

Table C-9. Radiobeacon System Characteristics (Signal-in-Space)

ACCURACY (2 Sigma)									
PREDICTABLE	REPEATABLE	RELATIVE	AVAILABILITY	COVERAGE	RELIABILITY	FIX RATE	FIX DIMENSION	SYSTEM CAPACITY	AMBIGUITY POTENTIAL
Aeronautical ± 3 -10°	N/A	N/A	99%	Maximum service volume - 75nm	99%	Continuous	One LOP per beacon	Unlimited	Potential is high for reciprocal bearing without sense antenna
Marine ± 3°	N/A	N/A	99%	Out to 50nm or 100 fathom curve					

SYSTEM DESCRIPTION: Aircraft nondirectional beacons are used to supplement VOR-DME for transition from en route to airport precision approach facilities and as a non-precision approach aid at many airports. Only low frequency beacons are considered in the FRP since there is little common use of the VHF/UHF beacons. Marine radiobeacons are used as homing beacons to identify the entrance to harbors. Selected marine beacons carry differential GPS data.

A. Signal Characteristics

Aeronautical NDBs operate in the 190 to 415 kHz and 510 to 535 kHz ARNS bands. (Note: NDBs in the 285-325 kHz band are secondary to maritime radiobeacons.) Their transmissions include a coded continuous-wave (CCW) or modulated continuous-wave (MCW) signal to identify the station. The CCW signal is generated by modulating a single carrier with either a 400 Hz or a 1,020 Hz tone for Morse code identification. The MCW signal is generated by spacing two carriers either 400 Hz or 1,020 Hz apart and keying the upper carrier to give the Morse code identification.

B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of ±3 to ±10 degrees. Achievement of ±3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations. For FAA flight inspection, NDB system accuracy is stated in terms of permissible needle swing: ±5 degrees on approaches and ±10 degrees in the en route area.

C. Availability

Availability of aeronautical NDBs is in excess of 99 percent.

D. Coverage

Extensive NDB coverage is provided by 1,575 ground stations, of which the FAA operates 728.

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The beacon provides continuous bearing information.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon. If within one range of two or more beacons, a two-dimensional fix may be obtained.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity that exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment that does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional navigation aid. For aviation radiobeacons, out-of-tolerance conditions are limited to output power reduction below operating minimums and loss of the transmitted station identifying tone. The radiobeacons used for nonprecision approaches are monitored and will shut down within 15 seconds of an out-of-tolerance condition.

C.2.8 Maritime Radiobeacons

Radiobeacons are nondirectional radio transmitting stations that operate in the low- and medium-frequency bands to provide ground wave signals to a receiver. An RDF is used to measure the bearing of the transmitter with respect to an aircraft or vessel.

There are 4 USCG-operated marine radiobeacons. These marine radiobeacons are expected to be phased out by the year 2000.

A. Signal Characteristics

Marine radiobeacons operate in the 285 to 325 kHz band. The signal characteristics for marine radiobeacons are summarized in Table C-9. Due to single carrier operations which eliminate the Morse tone identifier, USCG DGPS beacons do not conform to the traditional radiobeacon standards.

B. Accuracy

Positional accuracy derived from the bearing information is a function of geometry of the LOPs, the accuracy of compass heading, measurement accuracy, distance from the transmitter, stability of the signal, time of day, nature of the terrain between beacon and craft, and noise. In practice, bearing accuracy is on the order of ±3 to ±10 degrees. Achievement of ±3 degree accuracy requires that the RDF be calibrated before it is used for navigation by comparing radio bearings to accurate bearings obtained visually on the transmitting antenna. Since most direction finder receivers will tune to a number of radio frequency bands, transmissions from sources of known location, such as AM broadcast stations, are also used to obtain bearings, generally with less accuracy than obtained from radiobeacon stations.

C. Availability

Availability of marine radiobeacons is in excess of 99 percent.

D. Coverage

The coverage from marine radiobeacons has been steadily declining over the last four to six years. There is some evidence that privately maintained and operated beacons are still being used in the Gulf Coast region of the U.S. (e.g., homing beacons for oil rigs).

E. Reliability

Reliability is in excess of 99 percent.

F. Fix Rate

The beacon signal is provided continuously.

G. Fix Dimensions

In general, one LOP is available from a single radiobeacon.

H. System Capacity

An unlimited number of receivers may be used simultaneously.

I. Ambiguity

The only ambiguity that exists in the radiobeacon system is one of reciprocal bearing provided by some receiving equipment which does not employ a sense antenna to resolve direction.

J. Integrity

A radiobeacon is an omnidirectional navigation aid. Notification of outages is provided by a broadcast Notice to Mariners. Outages of long duration will also be published in the Local Notice to Mariners.

C.3 Navigation Information Services

C.3.1 USCG Navigation Information Service

The U.S. Coast Guard's Navigation Information Service (NIS), formerly the GPS Information Center, is the operational entity of the Civil GPS Service (CGS) that provides GPS status information to civil users of GPS. Its input is based on data from the GPS Control Segment, Department of Defense, and other sources. The mission of the NIS is to gather, process and disseminate timely GPS, Loran-C, and DGPS radionavigation information as well as general maritime navigation information.

The NIS Website also provides the user with information on policy changes or developments about radionavigation systems, especially GPS. It works as an arm of the CGSIC in the exchange of information between the system providers and the users by:

- Automatically disseminating GPS status and outage information through a listserver.
- Collecting information from users in support of the CGSIC and the GPS managers and operators.

Specifically, the functions performed by the NIS include the following:

- Act as the single focal point for non-aviation civil users to report problems with GPS.
- Provide Operational Advisory Broadcast (OAB) Service.
- Answer questions by telephone, written correspondence, or electronic mail.
- Provide information to the public on the NIS services available.
- Provide instruction on the access and use of the information services available.
- Maintain tutorial, instructional, and other relevant handbooks and material for distribution to users.

- Maintain records of GPS broadcast information, GPS databases or relevant data for reference purposes.
- Maintain bibliography of GPS publications.
- Develop new user services as required.

Information on GPS and USCG-operated radionavigation systems can be obtained from the USCG's Navigation Center (NAVCEN), 7327 Telegraph Road, Alexandria, VA 22315-3998. Table C-10 and Figure C-7 show the services through which the NIS provides Operational Advisory Broadcasts. NAVCEN's 24-hour hotline: (703) 313-5900. NAVCEN's E-mail address: webmaster@smtp.navcen.uscg.mil. Internet WWW address: http://www.navcen.uscg.mil/.

C.3.2 GPS NOTAM/Aeronautical Information System

The Air Force Flight Standards Agency has established a fundamental GPS Notice to Airmen (NOTAM) requirement for flight planning purposes. This requirement has been coordinated with the FAA and the other Services to be consistent with established flying procedures and safety standards for all DOD requirements.

On October 28, 1993, DOD began providing notice of GPS satellite vehicle outages through the NOTAM system. These NOTAMs are reformatted Notice Advisories to NAVSTAR Users (NANUs) provided by the 2nd Space Operations Squadron (2SOPS) at the GPS Master Control Station (MCS). The outages are disseminated to the NOTAM Office at least 48 hours before they are scheduled to occur. Unexpected outages also are reported by the 2SOPS to the U.S. NOTAM Office (USNOF).

Example: !GPS 07/010 GPS PRN 14 OTS
EFF 07160300-07161500

This NOTAM shows PRN 14 scheduled out of service on July 16 from 0300 until 1500 UTC. Satellite NOTAMs are issued as both a domestic NOTAM under the KGPS identifier and as an international NOTAM under the KNMH identifier. This makes the information accessible to both civilian and military aviators. Unfortunately, this information is meaningless to the pilot unless there is a method to interpret its effects on availability for the intended operation.

Use of GPS for Instrument Flight Rule (IFR) supplemental air navigation requires that the system have the ability to detect when a satellite is out of tolerance and should not be used in the navigation solution. This capability is provided by Receiver Autonomous Integrity Monitoring (RAIM), an algorithm contained within the GPS receiver. All receivers certified for supplemental navigation must have RAIM or an equivalent capability.

Table C-10. NIS Services

Service	Availability	Information Type	Contact Number
NIS Watchstander	24 hours	User Inquiries	(703) 313-5900 FAX (703) 313-5920
Internet	24 hours	Status Forecast, History, Outages NGS Data, FRP and Miscellaneous Information	http://www.navcen.uscg.mil ftp://ftp.navcen.uscg.mil
NIS Voice Tape Recording	24 hours	Status Forecasts Historic	(703) 313-5907
WWV	Minutes 14 & 15	Status Forecasts	2.5, 5, 10, 15, and 20 MHz
WWVH	Minutes 43 & 44	Status Forecasts	2.5, 5, 10, and 15 MHz
USCG	When broadcast	Status Forecasts	Maritime VHF Radio Band
NIMA Broadcast Warnings	When broadcast received	Status Forecasts	
NIMA Weekly Notice to Mariners	Published & mailed weekly	Status Forecasts Outages	(301) 227-3126
Navinfonet Automated Notice to Mariners system	24 hours	Status Forecasts Historic Almanacs	(301) 227-3351/ 300 baud (301) 227-5925/ 1200 baud (301) 227-4360/ 2400 baud
NAVTEX Data Broadcast	All stations broadcast 6 times daily at alternating times	Status Forecasts Outages	518kHz (301) 227-4424/ 9600 baud

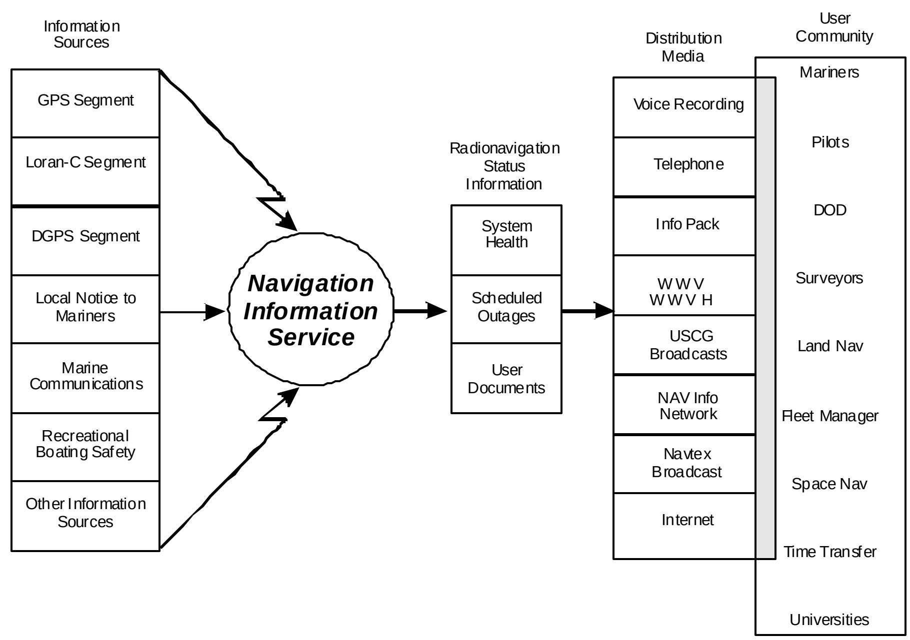

Figure C-7. NIS Information Flow

In order for the receiver to perform RAIM, a minimum of five satellites with satisfactory geometry must be visible. Since the GPS constellation of 24 satellites was not designed to provide this level of coverage, RAIM is not always available even when all of the satellites are operational. Therefore, if a satellite fails or is taken out of service for maintenance, it is not intuitively known which areas of the country are affected, if any. The location and duration of these outage periods can be predicted with the aid of computer analysis, however, and reported to pilots during the pre-flight planning process. Notification of site-specific outages provides the pilot with information regarding GPS RAIM availability for nonprecision approach at the filed destination.

Site-specific GPS NOTAMs are computed based on criteria in the RTCA/DO-208, "Minimum Operational Performance Standards for Airborne Supplemental Navigation Equipment Using Global Positioning System (GPS)," dated July 1991, and FAA Technical Standard Order (TSO)-C129(a), "Airborne Supplemental Navigation Equipment Using the Global Positioning System (GPS)." The baseline RAIM algorithm, as specified in the MOPS and TSO, is used for computing the NOTAMs for GPS.

GPS almanac data are received via an antenna on the roof of the FAA or sent by modem from the GPS Master Control Station to a computer at the U.S. NOTAM Office. The almanac and satellite health status data are input into the RAIM algorithm and processed against a database of airfields to determine location specific outages. The outage information is then distributed in the form of a NOTAM to U.S. military aviators and as aeronautical information to U.S. Flight Service Stations for civilian aviators. This occurs daily for an advance 48-hour period or whenever a change occurs in a satellite's health status.

The military GPS NOTAM system was officially declared operational on May 16, 1995. An example military NOTAM output from the system sent through NATCOM to the Aviation Weather Network (AWN) to the CONUS Meteorological Distribution System (COMEDS) and the Automated Weather Distribution System (AWDS) is shown below:

a) KLAX
b) 11041700
c) 11041745
d) GPS ONLY NPA NOT AVBL

This NOTAM means that a GPS nonprecision approach at Los Angeles International airport is unavailable on Nov. 4 from 17:00 to 17:45.

The FAA provides similar GPS outage information in an aeronautical information format, but not as a NOTAM. The FAA uses the same GPS NOTAM generator as the DOD to compute their aeronautical information, but it is distributed through their two Automated Weather Processors (AWPs) to the 21 Flight Service Data Processing Systems (FSDPS) and then to the 61 Automated Flight Service Stations (AFSS), as shown in Figure C-8. The FAA's GPS aeronautical information became operational November 2, 1995. GPS availability for an NPA at the destination airfield is provided to a pilot upon request from the AFSS. The pilot can request information for the estimated time of arrival or ask for the GPS availability over a window of up to 48 hours.

NOTAM information applicable to additional phases of flight may be accommodated in the future. Since GPS is an area navigation system, GPS outage information may be provided using a graphical display, similar to that used to convey weather information.

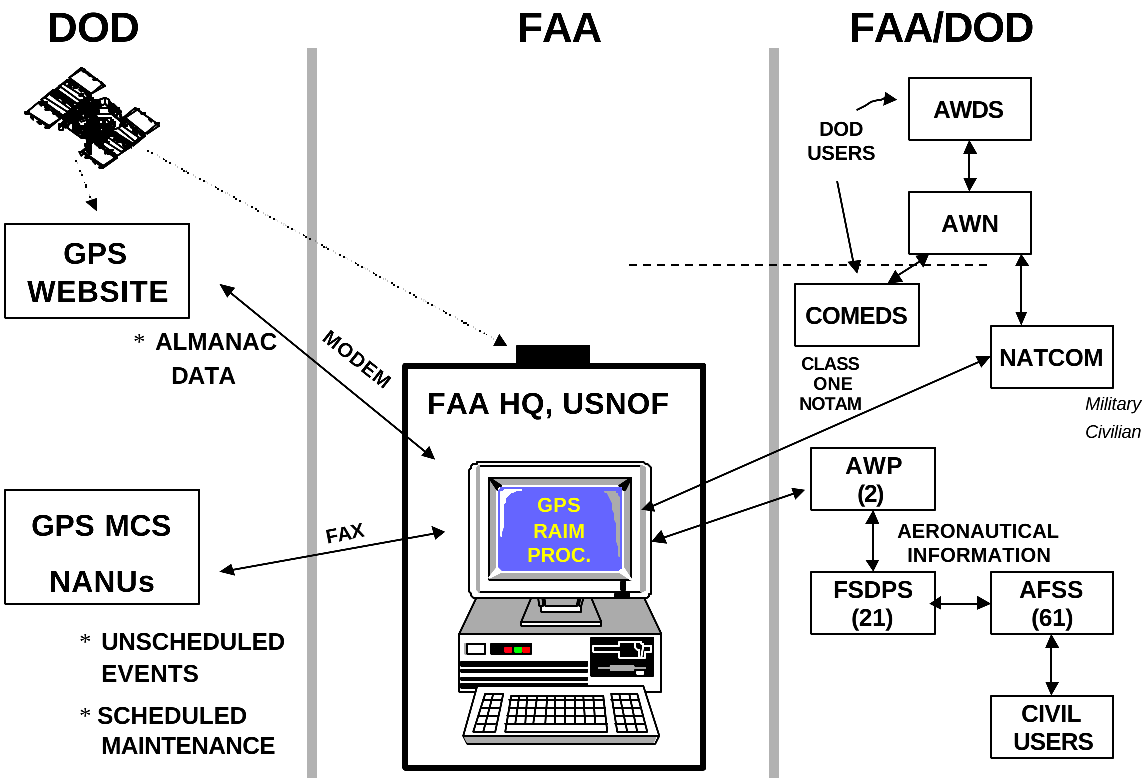

Figure C-8. GPS NOTAM/Aeronautical Information Distribution System